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ABSTRACT

Recent technological advances now make possible full integration of sound in instructional software. This paper explores the systematic use of sound to enhance learning and the operations and limiting factors of information-processing. It illustrates a model of the "instructional communication system" based on a combination of information-processing and communication theories. The model identifies and characterizes the way sound might be used to optimize learning from multimedia instruction. (Contains 45 references and 11 figures.) (Author/AEF)

A Model for the Efficacious Use of Sound in Multimedia Instruction

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Abstract

Recent technological advances now make possible full integration of sound in instructional software. This paper explores the systematic use of sound to enhance learning. It illustrates a model of the "instructional communication system" based on a combination of information-processing and communication theories. The model identifies and characterizes the way sound might be used to optimize learning from multimedia instruction.

Technological and cost barriers to full integration of sound in instructional software have recently disappeared. Conceptual and preconceptual barriers, however, still appear to prevent software designers from using sound more effectively in their instructional products. Interface books seldom discuss the use of sound, and when they do, the use most often discussed is simple verbatim narration of on-screen text (see Bickford, 1997; Cooper, 1995; Galitz, 1997; Mandel, 1997). Because most "classics" of instructional interface design were written before sound was a viable design component, sound is seldom well discussed (see Alessi & Trolip, 1985, 1991; Hannafin & Peck, 1988; Jonassen, 1988; Keller, 1987). In general, interface design guidelines identify three main uses of sound in instructional software: to alert learners to errors, to provide stand-alone examples (like musical passages or digitized versions of speeches), or to narrate text on the screen (for redundant presentation, for non-readers, or for those with auditory limitations). Review of research on sound in instructional software reveals a focus on the third use cited above, digitized or computer-generated synthetic speech narration (see Barron & Atkins, 1994; Mann, 1995; Shih & Alessi, 1996). While some outside education have considered non-speech interface sounds (Blattner, Sumikawa, & Greenberg, 1989; Gaver, 1986), many promising uses remain unexplored.

Before one can determine sound's potential contribution to instructional software, however, one must have a clear picture of the component processes involved in learning. Therefore, this paper begins by exploring the operations and limiting factors of information-processing.

Information-processing Operations and Limiting Factors

According to information-processing theory, learning emerges from processing interactions among information from the environment and the learner's knowledge and previous experiences. Most theorists have adopted at least the basic structure of the three-stage memory model first proposed by Atkinson and Shiffrin in 1968.

The Atkinson-Shiffrin Information-processing Model

In the Atkinson-Shiffrin model, environmental stimuli in their primitive form are first handled by a sensory information store, or *sensory register*. Signals held here are readily displaced by subsequent signals in the same sensory channel. The sensory register filters and then routes incoming signals to a second, *short-term store* where information is held temporarily until it can be encoded for storage. *Encoding* is the process of building relationships and connections within new material or between new material and existing knowledge structures. Once encoded, the information is moved into *long-term store* in the form of *images* (the autobiographical knowledge or *episodic memories* one has for things that have been personally experienced) or *schemas* (the organized, propositional knowledge one has for the meanings, rules, and algorithms used to manipulate and understand the many symbol systems encountered in life) (Tulving, 1972). Long-term store is both the place where we hold newly encoded information and the place from which we retrieve well-established memories. Recovering information from long-term store requires *cues* that may be supplied externally by the situation or internally by one's existing memories. These cues are used to search long-term store in order to identify and retrieve matches. *Control processes* "oversee" the cognitive system by regulating the exchange of information between the sensory register and long-term store, determining which search-and-retrieval strategies to use to access information from long-term store, and deciding when sufficient information has been retrieved.

Information-processing theorists maintain that learning occurs when information that has been transferred to and stored in long-term memory can be retrieved when needed. Transforming incoming environmental stimuli into learned images and schema involves three main operations: acquisition, processing, and retrieval. It appears, however, that limitations in each of these operations may restrict the amount of data one can store long-term.

Limiting Factors in Information Processing

In order to acquire or make sense of the constant barrage of sensory information, an individual must decide, often unconsciously, which information to attend to and which to ignore. To explain this phenomenon, Broadbent (1958) posited that all information reaching the sensory register is subjected simultaneously, or in parallel, to a preliminary analysis based on prior knowledge. From this pre-perceptual analysis of the entire sensory scene, one chooses a smaller subset of stimuli to process successively, or in serial, through the rest of the cognitive system. The "bottleneck" created between parallel pre-perceptual and serial perceptual stages restricts the amount of information entering the cognitive system. Individuals remain essentially unaware of information not selected for attention.

Like many later researchers, Wundt (1896/1897) found short-term store is also of limited capacity: There is a limit to the amount of information, or maximal *cognitive load*, an individual can process in short-term store at any given time. Although it may be that cognitive load varies somewhat, depending upon the nature of input stimuli, our capacity for processing incoming data is certainly limited to some finite quantity. Information that exceeds cognitive processing capacity is dropped from short-term store without being processed. Further, unless information that enters the store is rehearsed, it decays within approximately five to twenty seconds. Short-term store limitations dictate that data not encoded and moved into long-term store must be overwritten to make room for new incoming stimuli (as when we forget a new phone number after hearing another series of numbers) or consciously rehearsed and then discarded immediately after use (as when we repeat a telephone number aloud until we have dialed it).

Memories often seem to fade with the passage of time. Forgetting is a failure to retrieve information from long-term store. There are three general hypotheses about the factors that cause forgetting, each of which probably contributes to overall retrieval problems. The decay hypothesis asserts that the strength of a memory simply weakens over time and therefore is harder to retrieve (Wickelgren, 1976). The interference hypothesis claims that competition among memories blocks the retrieval of a target memory (Postman, 1961). The retrieval-cue hypothesis asserts that at the time of retrieval we lose access to the internal "indices" that point to the memory's location in long-term store (Norman, 1982). There is some evidence to suggest that once information has been moved to long-term store, it remains there forever (Nelson, 1971). While this means memories may never actually leave long-term store, individuals certainly can lose access to them.

Berlo (1960) suggested that the study of learning processes and the study of communication processes differ only in their point of view. While learning models generally begin with and focus on how messages are received and processed by learners, communication models most often begin with and focus on how messages are sent. Learning from instructional software, therefore, might be viewed as an *instructional communication system* with a set of interrelated parts working together to produce learning (Banathy, 1996).

Communication Operations and Limitations

Communication is the transmission, reception, and decoding of signals. As was the case with information-processing theory, one model —Shannon and Weaver's *The Mathematical Theory of Communication* (1949/1969)— appears to have been particularly influential in shaping communication theory.

The Shannon-Weaver Communication Model

The Shannon-Weaver model proposes that all communication processes begin when a *source*, desiring to produce some outcome, chooses a message to be communicated. The message is encoded to produce a signal appropriate for transmission over the *channel* that will be used. After the message has been transmitted, a *receiver* then decodes the message from the signal transmitted. All channels have limited capacity. In humans, *channel capacity* generally refers to the physiological and psychological limitations on the number of symbols or stimuli that individuals can process. When more symbols are transmitted than a channel can handle, some information is lost.

According to Shannon and Weaver, communication is "perfect" when the information contained in a message affects the receiver in exactly the way intended by the source. Communication is rarely perfect, however; at any point things can get added to the signal that were not originally intended by the source. This spurious information, or *noise*, introduces errors that increase the uncertainty in the situation and make the signal harder for the receiver to reconstruct accurately.

Limiting Factors in Communication

Shannon and Weaver divided the analysis of communication problems into three levels. "Level A" deals with how accurately the signal is received. When competing external or internal stimuli exist in a communication channel, the resulting noise introduces technical errors that can overpower all or part of a signal transmission. This disruption prevents the receiver from being able to select the communicated signal for decoding. No matter how accurately a message is transmitted, however, if it cannot be decoded by the receiver it is not likely to convey the

intended message. "Level B," therefore, concerns how precisely the received signal conveys the intended message. Decoding requires the receiver to analyze an incoming signal based on his or her existing schemas. When no interpretive framework exists and none is supplied by the source, the resulting noise introduces semantic errors that prevent the signal from conveying the intended message. Even when a message is interpreted correctly, it still may not accomplish the source's goal. Thus, "Level C" involves whether the received message ultimately produces the outcome desired by the source. To effect an outcome, the elements and structure of the message that assign connotative meaning —such as aesthetic appeal, style, execution, and other psychological and emotional factors—must mesh with the receiver's own relevant beliefs, cultural values, and experiences. If this synthesis leads the receiver to make inferences about the message that are not intended by its source, the resulting noise introduces conceptual errors that can prevent the communication from producing the desired result.

Although Shannon and Weaver confined their work primarily to the study of Level A problems of mechanistic communication systems, they contended that improving the effectiveness and efficiency of the communication process overall requires applying concepts from their model to all three levels of communication problems. Their work suggested that there may be ways to anticipate communication difficulties and "front load" messages with the cues necessary to "squelch" noise even before it occurs.

Using Sound to Squelch Noise in Instructional Communication Systems

Sounds can support learning in a variety of ways. They can gain and focus learners' attention, reducing the distraction of competing stimuli, engaging interest over time, and making environments more tangible and emotionally arousing (Kohfeld, 1971; Bernstein, Clark, & Edelstein, 1969; Thomas & Johnston, 1984). They can help learners condense, elaborate upon, and organize details about their surroundings, helping them to see interconnections among new pieces of information (McAdams, 1993; Winn, 1993; Yost, 1993). They can provide a familiar setting that may help learners relate incoming information to existing knowledge (Deutsch, 1980, 1986; Gaver, 1993). Thus, McAdams and Bigand (1993) argued that sound is uniquely suited to assist in the acquisition, processing, and retrieval of new information for those who are not hearing-impaired. If this is true, there may be systematic ways to design *multi-cue* instructional messages that overcome information-processing noise and optimize learning.

The Role of Multi-cue Messages in Instructional Communication Systems

For some time it has been thought that simply adding cues to messages might improve the effectiveness of instructional communication. The idea behind *cue summation* is that the more cues used, whether within or across sensory channels, the greater the amount of information communicated and the more learning gained. While the results of cue summation studies appear contradictory on the surface, Severin (1967) maintained the differences might be explained by the degree of redundancy among cues used in the treatments. Severin noted that studies that found no difference between multiple-cue and single-cue communication used cues that were <u>almost totally redundant</u>, such as text coupled with word-for-word narration. In these studies the wedded cues apparently neither competed with each other nor supplied new information. In contrast, studies that found multiple-cue communications less effective than single-cue communications used cues with no redundancy between them, such as text coupled with unrelated speech. In these studies, the dueling cues probably exceeded channel capacity, producing noise that decreased communication efficiency. Severin concluded that studies that found multi-cue communications to be more effective than single-cue communications used cues that were <u>partially redundant</u>, like pictures coupled with related narration. In these studies, primary and secondary cues appear offset just enough for the secondary cue to supply the right balance of redundancy and new information. Severin contended that multi-cue messages can be designed to help improve instructional communication. The question is not just whether the message contains multiple cues, but whether those secondary cues supply the optimal amount of redundancy.

The Role of Redundancy in Instructional Communication Systems

Redundancy is the information message cues share: the parts that "overlap." For example, a source might attempt to correct technical problems in the system (Level A) by retransmitting or amplifying the signal. This content redundancy often can help overcome transmission errors by completing obstructed signals or by preventing the interference in the first place. A source anticipating semantic problems in the system (Level B) might attempt to correct them by supplying the relevant connections between and among related message signals. This context redundancy often can help overcome misinterpretations by furnishing denotative meanings for signals. A source might attempt to correct conceptual problems in the system (Level C) by carefully choosing signals that make appropriate links to receivers' preexisting concepts in memory. This construct redundancy clarifies the connotative meanings behind message signals and reduces misunderstandings.

When a source anticipates noise at the various levels of communication, the trick may be in knowing how much and which sort of between-cue message redundancy to include in order to counteract noise. Striking this optimal balance may also be the key to successful instructional communication. Further, it appears that multi-cue

instructional messages incorporating sound might both deliver sufficient amounts of new information and supply the noise-defeating content, context, and construct redundancy necessary to enhance learning. Theories of system optimization, such as that presented by Wilde and Beightler (1967), recommend creating a model of the system in order to understand precisely what the system must do to accomplish its goal. This model might then serve as a frame of reference for subsequent evaluation of the system.

Modeling the Instructional Communication System

Understanding the underlying component processes of instructional communication might begin by adding the receiver's information-processing transactions to the Shannon-Weaver model. Figure 1 depicts the receivers' component processes in more detail, illustrating an idealized representation of the three levels of communication as three learning *phases* (select, analyze, and synthesize) and depicting instructional communication limitations — channel capacity and noise— as constraints on the system.

If we were trying to discover only what output the system produces for a given mixture and amount of input, this "black box" model might be adequate. However, our concern here is to determine what amounts and mixtures of input at each phase of learning will bring about the kinds of system activity necessary to produce optimal learning output (Churchman, 1968). In order for us to understand how input might affect instructional communication, the model must approximate more closely the complex circles of influence that exist among the proposed learning phases, the system's component information-processing operations, and the human-communication system constraints. Figure 1 neither depicts the role that acquisition, processing, and retrieval operations play in each learning phase nor suggests how the system might utilize the content, context, and construct redundancy in an instructional message to help the receiver overcome system constraints.

In order to explore the area inside the boxes, it might be useful to move from the traditional flow-chart type of diagram toward a structural illustration that approximates more closely the more dynamic nature of the instructional communication system. The model illustrated in Figure 2 and in subsequent figures in this chapter

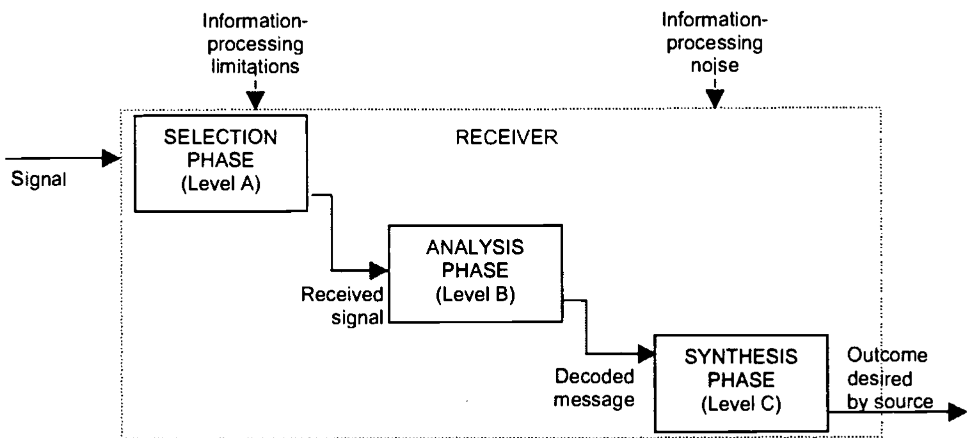

Figure 1. Idealized information-processing explanation for receiver learning transactions.

draws parallels between the instructional communication system and the process of crystal formation in chemistry.

Thus, Figure 2 eliminates the traditional boxes and arrows in favor of a grid of intersecting lines that represents learning phases and operations as an instructional message moves through the instructional communication channel. The

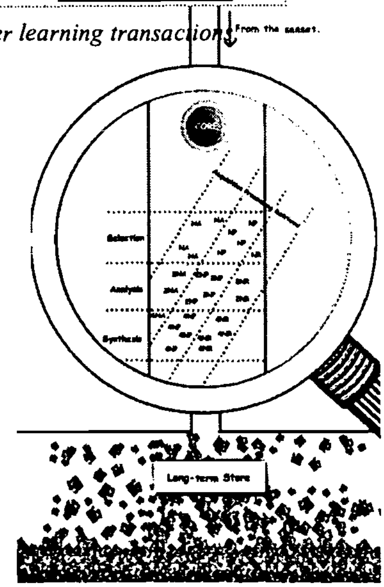

Figure 2. A representational illustration of the instructional communication system.

channel is drawn as the area between two parallel lines running vertically from the top to the bottom of the diagram. The message is represented as a set of increasingly lighter concentric circles (moving from inner *core* to outer circle). The areas between the lines running horizontally from left to right represent the three transactions or "phases" of learning —selection, analysis, and synthesis— identified for use in the earlier, linear model. This is the learner's working memory. The areas between the channel lines running diagonally (from lower-left to upper-right) represent the three information-processing operations that the receiver uses at each phase of learning in order to process the instructional signal.

The dividing lines between acquisition, processing, and retrieval dissect the channel diagonally in order to illustrate how each operation is applied in varying amounts at each learning phase. Processing is depicted as the middle of the three because it relies on acquisition and retrieval to supply the information and memories it acts upon. During selection, processing calls upon acquisition heavily; in contrast, only the most salient memories are retrieved during selection. During analysis, processing is central —although acquisition and retrieval are also relatively active. During synthesis, processing calls upon retrieval most heavily, while only the most salient new stimuli are acquired.

The area at the bottom of the model represents long-term store, with its schema particles "suspended" and "fluid." These schemas are retrieved from memory to help learners make sense of new information. The particles in the long-term store suspension are not disordered; related crystals naturally gravitate toward one another and may align to form more complex and interdependent structures. The extent to which particles remain suspended and fluid, however, depends upon how often they are "agitated." Particles that have just recently been stored or retrieved from memory waft to the top of long-term store, carrying others around them along in their wake. This activity makes these memories easily accessible to working memory and likely to be among the first retrieved in later learning situations (Norman, 1982). Schema particles suspended in long-term memory will settle slowly if left stagnate. Unless schemas occasionally are retrieved from long-term store and the "silt" stirred up, they become too deeply embedded and are forgotten. Stagnate memories lack the fluidity to be applied to new learning situations.

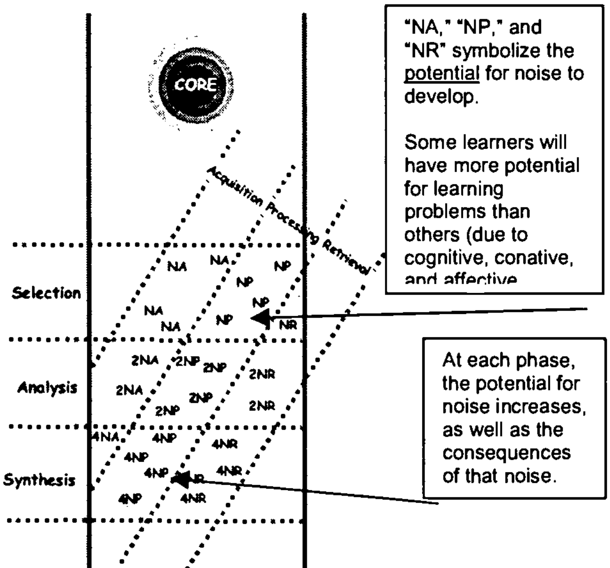

Figure 3. Redundant message enters channel filled with the potential for developing noise.

Because of the inevitable differences among learners' characteristic cognitive, conative, and affective traits, the instructional communication channel is always prone to noise (Corno & Snow, 1986). For example, the same instructional method that gains one learner's attention may not gain another's (Biehler & Snowman, 1982). Some learners will lack the prior knowledge they need to help them make sense of the new information (Rumelhart & Norman, 1981). Still other learners may be unable or unwilling to apply their knowledge mindfully when appropriate (Langer, 1989). The potential for acquisition, processing, and retrieval noise in the selection phase is depicted in Figure 3 as "NA," "NP," and "NR," respectively. (Despite possible similarities between the letter code representations used in the model and the names of actual chemical elements, such letter codes here do not represent such elements.)

At each deeper phase of learning, the relative "strength" of potential noise as well as the ultimate consequences of that noise increase by some factor. For example, while it can be difficult to overcome acquisition noise at selection in order to gain a learner's attention, it often is much harder to overcome acquisition noise in analysis in order to focus a learner's attention, and harder still to hold a learner's attention over time for synthesis. While there is no way to know the actual

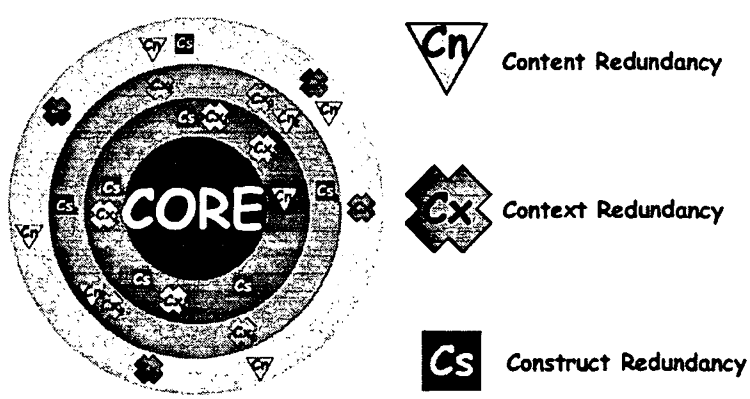

Figure 4. Message contains three layers of "solute" with varying amounts of content, context, and construct redundancy "molecules."

proportions/concentrations of noise at each phase, for purposes of illustration, the authors depicted the potential for acquisition, processing, and retrieval noise as "NA," "NP," and "NR" in the selection phase, "2NA," "2NP," and "2NR" in the analysis phase and as "4NA," "4NP," and "4NR" in the synthesis phase. Similarly, because the proportion of acquisition, processing, and retrieval noise potential is likely to be closely related to the proportion of acquisition, processing, and retrieval involved at each learning phase, acquisition noise potential at selection is depicted using 4 "units" as compared with 1 "unit" of acquisition noise potential at synthesis. Conversely, retrieval at selection is depicted as fairly low (1 "unit") whereas it is comparatively high at synthesis (4 "units"). The potential for processing noise remains the same at each learning phase (4 "units").

Figure 4 supplies a closer look at the instructional message. The black circle labeled "CORE" represents the entropic, core knowledge that the instructional message is intended to convey. The increasingly lighter circles around the core (moving from inside to outside) represent its layers of redundancy that have been "formulated" for each learning phase. Figure 6 depicts the ratio of content, context, and construct redundancy "molecules" that would be appropriate for the learning situation depicted in Figure 3. That means the number of redundancy molecules within each ring are balanced for the information-processing needs of its intended learning phase and the potential for channel noise given the audience and the content. Recall, however, that the proportions/concentrations used here are merely for illustration.

As depicted in Figure 5, when an instructional message enters the selection phase of working memory its first layer of redundancy dissolves. Depending upon the learner's ability or willingness to exert information-

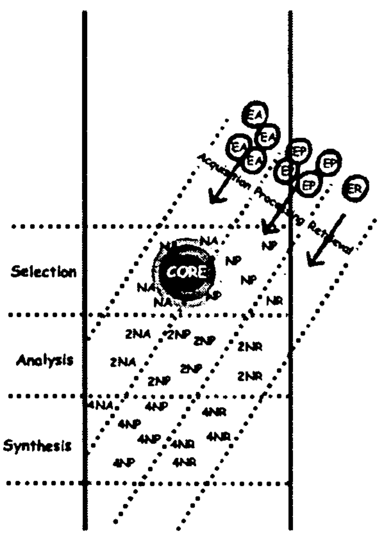

Figure 5. First redundancy layer dissolves stimulating selection-level information-processing.

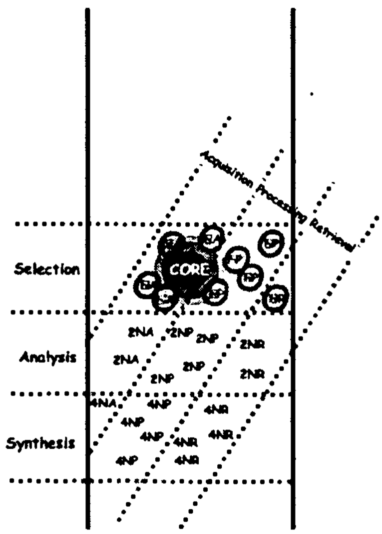

Figure 6. Information-processing effort "reacts" with potential noise and the redundancy in the message.

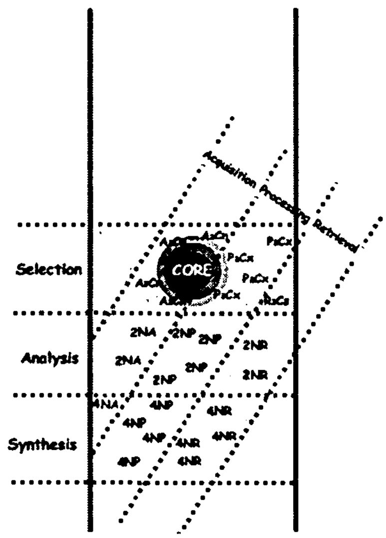

Figure 7. Noise potential is "neutralized."

processing effort, the content, context, and construct *solute* stimulates the production of acquisition, processing, and retrieval *ions* ("EA," "EP," and "ER," respectively). When these ions are added to a *solution* that already contains redundancy dissolved from the message (Cn, Cx, and Cs), and various forms of information-processing noise potential (NA, NP, and NR), three "chemical reactions" occur (Figure 6). These reactions theoretically could be depicted mathematically:

$$NA + Cn + EA \rightarrow A_2Cn + NE$$
$$NP + Cx + EP \rightarrow P_2Cx + NE$$
$$NR + Cs + ER \rightarrow R_2Cs + NE$$

The first formula means that when the potential for acquisition noise is combined with content redundancy and the learner's effort to acquire the material, the resulting products are gained attention (A_2Cn) and residual positive affects of learning, such as improved attitudes and feelings of success, that serve as *catalysts* for continued learning(NE, as in "noise + energy"). The second formula indicates that when the potential for processing noise is combined with context redundancy and the learner's effort to process the material, the resulting products are isolated relevant stimuli (P_2Cx) and more *positive residual* (NE). The third formula indicates that when the potential for retrieval noise is combined with construct redundancy and the learner's effort to retrieve schemas from long-term store, the resulting products are retrieval of the appropriate constructs from memory (P_2Cx) and still more NE. The final outcome of successful selection-level processing is depicted in Figure 7. At this point in the instructional communication system, the learner is interested in the message and has selected it for further processing. Further, higher concentrations of NE make the working memory solution thicker, slowing the message and allowing deeper processing.

Similar reactions occur in the analysis phase. Once again, using our hypothetical proportions/concentrations, the analysis reactions might be depicted like this:

$$2NA + Cn_2 + EA \rightarrow A_4Cn_2 + 2NE$$
$$2NP + Cx_2 + EP \rightarrow P_4Cx_2 + 2NE$$
$$2NR + Cs_2 + ER \rightarrow R_4Cs_2 + 2NE$$

Analysis-level reactions yield focused attention (A_4Cn_2), information organizing and categorizing (P_4Cx_2), efforts to build upon existing knowledge (R_4Cs_2) and even higher levels of positive residual (2NE). At this point in the instructional communication system, the learner is curious about the message and is actively analyzing its meaning. Further, higher concentrations of NE continue to make the working memory solution thicker and decrease message speed.

Finally, the synthesis reactions employing our hypothetical proportions/ concentrations, might look like this:

$$4NA + Cn_4 + 4EA \rightarrow A_8Cn_4 + 4NE$$
$$4NP + Cx_4 + 4EP \rightarrow P_8Cx_4 + 4NE$$
$$4NR + Cs_4 + 4ER \rightarrow R_8Cs_4 + 4NE$$

The product of synthesis-level reactions is attention held over time (A_8Cn_4), elaboration upon the new information (P_8Cx_4), construction of more transferable knowledge structures (R_8Cs_4), and still higher levels of positive residual (2NE). At this point in the instructional communication system, the learner is engaged in the message and is affected by its larger meaning. Still higher concentrations of NE continue to "thicken" the solute and slow the message's passage through the system, fostering deeper processing.

Thus, as each layer of carefully chosen redundant material dissolves, the message "solute" acts to "neutralize" the acquisition, processing, and retrieval noise in that phase. In Figures 5-7, the first layer of redundancy dissolves into the learning "solution" and, with the learner's help, the solute counterbalances errors caused by acquisition, processing, and retrieval noise in the selection phase. Here, the instructional signal provides redundant message cues aimed primarily at helping the learner **select** the instructional signal. Similarly, the second layer of redundancy in an instructional message can reduce the effects of acquisition, processing, and retrieval noise in the analysis phase when the learner exerts information-processing effort. Now, the instructional signal includes message cues intended to help the learner **analyze** the message. In the final phase, the third layer of message redundancy, in conjunction with even greater information-processing effort on behalf of the learner, neutralizes acquisition, processing, and noise at the synthesis phase. Here, the instructional message includes cues that help the learner to **synthesize** the content of a message.

By the time the message has reached the synthesis phase, all redundant layers have dissolved and the learning "solution" has reached its *saturation point*. Meanwhile, the learner ideally has become a more motivated participant in the learning (NE) and is thinking deeply about the material. This state of engagement thickens the

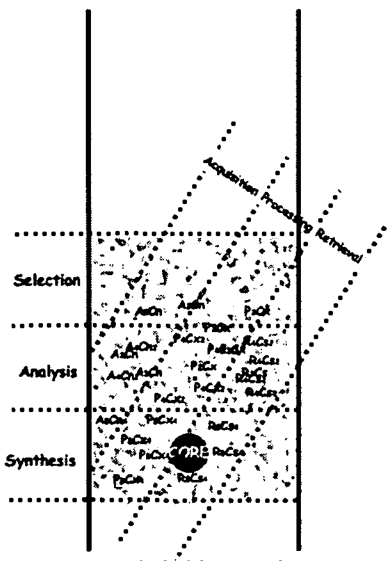

Figure 8. While held in synthesis, the core begins to attract solute from saturated solution.

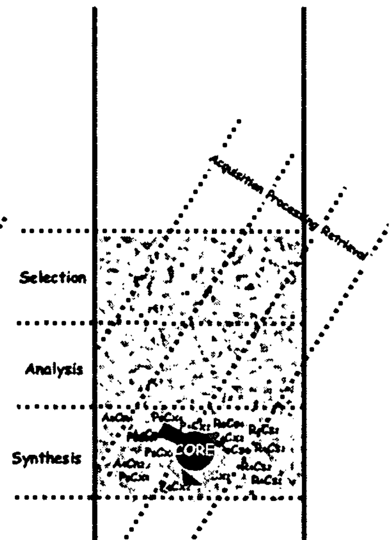

Figure 9. Schema grows, pulling together surrounding elements in the channel.

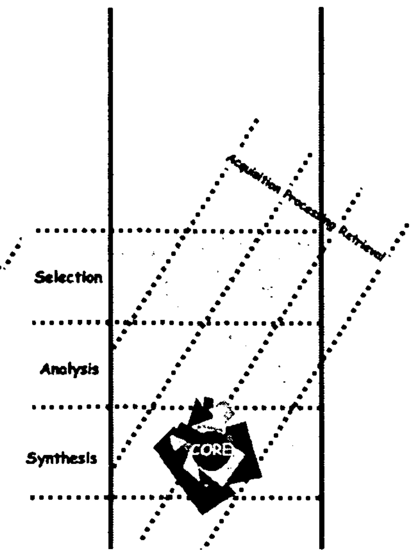

Figure 10. A schema, unique to the learner, is formed, leaving behind some of the positive affects of learning (NE).

saturated learning solution and slows the message to a stop. These conditions, when they exist, set the stage for the core knowledge to *seed* the development of a crystallized schema. Figures 8, 9, and 10 illustrate how the message held in synthesis —now dissolved down to its core knowledge— "crystallizes" into a schema in the enriched solution. During synthesis, learners draw upon the acquired content, processed contexts, and retrieved constructs that are the products of the chemical reactions at each learning phase. Learners use these materials to build and develop their own structures, or "crystallized" understandings of the core knowledge conveyed in the message. Like crystals, no two schemas are alike; each schema formed will be unique to the learner. Thus, as the message moves through the learning phases, it is processed more deeply until it forms a new schema. That schema is then passed on to long-term storage.

When a message with very little redundancy enters the system, it is likely to run into instructional communication problems at each learning phase. Messages with insufficient selection-level content, context, and construct redundancy do not evoke enough information-processing effort from the learner to overcome all of the potential for noise. Likewise, these "chemical reactions" produce very little positive residual (NE) to slow message transit. As the accelerating message reaches the analysis phase, the little analysis-level redundancy it contains fails to neutralize still more noise potential and doesn't slow the message down for deeper processing. By the time the message speeds through synthesis, its lack of redundancy has left noise potential behind in each learning phase.

While it is possible for the learner to defeat some of the noise potential and slow the message for deeper processing without the aid of redundancy, the chemical reaction "formulas" suggest that this will likely require that the learner supply more than just self-motivated information-processing effort. In order to yield sufficient amounts of positive residual to slow the message, the learner will probably also have "fill in" the Cn, Cx, and Cs parts of the equation with dedicated attention, preexisting strategies for processing the new information, and prior understandings of the topic. Further, if any channel noise potential is not overcome during processing, it

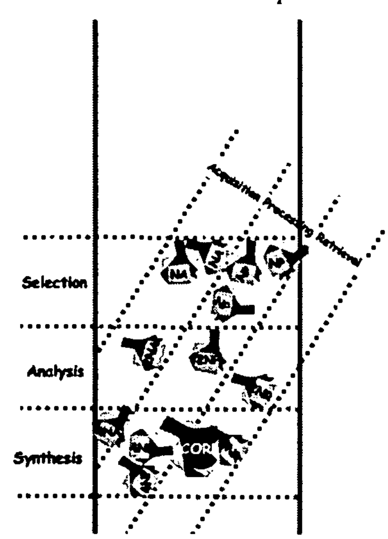

Figure 11. Even if the core remains in the channel long enough to crystallize, potential noise remaining in the channel may also act as "seeds," increasing the uncertainty in the situation.

will crystallize along with the core during synthesis, depriving the *message crystal* of needed solute. Ultimately, the errant structures increase the uncertainty in the situation, making it difficult for the learner to separate the deprived core knowledge structure from the noise (see Figure 11).

The more likely scenario, however, is that the weight and density of a message with very little redundancy will cause it to pass through the system unimpeded and largely unprocessed. If a learner is not interested in, curious about, or engaged by what dissolves from the message, he or she will not exert the information-processing effort that slows it down at each learning phase for deeper processing and reflection. While what's left of the message core may actually end up somewhere in long-term store, its mass and velocity mean that —if it can subsequently be located— it may well be buried too far out of reach to be easily retrieved.

Like message schemas, the noise that crystallizes in the channel eventually begins to make its way into long-term store, leaving behind even more potential for noise in subsequent learning. When noise structures (misinterpretations, misunderstandings) find their way into long-term store, they can be difficult to extract later. Instructional technologies that are not "front loaded" to subdue acquisition, processing, and retrieval noise are unlikely to produce outcomes that match their goals (Dick & Carey, 1990). Effective instructional designers recognize this problem and build into the message the redundancies needed to resolve those problems should they occur. Sound may play a role in such design. This model may help to illustrate that role by clarifying the operations and limiting factors within the instructional communication system.

A Cautionary Note: The Function of a Model

The model we propose is intended to help the reader conceptualize the role of redundancy in enhanced message transmission. Britt (1997) maintained that a model —through simplification, explicitness, and reformulation— provides an effective way to sort out the chaos of systems that are too complex to deal with directly. Because explicit systems models can show the repeating patterns and relationships among the parts, they can help one understand the true complexity of the problem or situation. Salisbury (1996) argued that to be useful, however, a model must represent all of the system's components and the relationships between them simply enough to be understandable. The model must reduce complexity and ambiguity sufficiently so as to make analysis and the prediction of system behavior possible. But simplifying real-world complexity poses a dilemma. If a model is too simplistic, the relationship of the model to its real-world counterpart becomes tenuous. When this occurs, predictions of system behavior based on the model can be grossly inaccurate. Thus, we cannot expect to model a system precisely. Modeling is not about precision but, instead, about tentatively determining which things are important to consider in capturing the essence of the system. A model cannot provide final answers. As knowledge is accumulated and relevant areas of the modeled system are clarified, the model is almost always modified.

We suggest that this model may prove useful in deciding how to incorporate message redundancy through the use of sound cues in instructional software. Before one can do that, however, the model's assumptions should be tested against what is known about "real world" instructional software. This should help to explicate the model and reveal more specific ways sound might be used to improve the effectiveness and efficiency of the instructional communication system.

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